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ABSTRACT

In most classrooms science has been presented as an inert body of knowledge to be assimilated rather than a process of inquiry and a way to make sense of our world. This traditional approach has allowed teachers to cover a great many topics but the quality of learning that it has yielded has proven disappointing. This article outlines some major reform efforts aimed at changing that situation including: the Scope, Sequence, and Coordination (SS&C) of Secondary School Science projects; Project 2061; and the new National Science Education Standards and describes their impact using examples from classroom observations. The related views of some science educators are also presented. Contains a list of nine organizations that can provide resources for improving science education. (JRH)

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Curriculum Update

Association for Supervision and Curriculum Development

Reinventing Science Education
Reformers Promote Hands-On, Inquiry-Based Learning

By Scott Willis

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CURRICULUM UPDATE

Reinventing Science Education

Reformers Promote Hands-On, Inquiry-Based Learning

BY SCOTT WILLIS

In Lisa Nyberg's classroom at Brattain Elementary School in Springfield, Ore., 3rd and 4th graders are learning about simple machines. The classroom is a flurry of activity, as children take apart broken toasters and other household appliances, trying to identify the simple machines within. Students examine and test the mechanical workings intently, discussing their ideas with their partners. A child disassembling a tape recorder forms the theory that pushing a certain button works a switch. Another child is consulting the resource books scattered around the room, searching the index of *How Things Work* for "vacuum cleaners." When the children discover inexplicable components—such as electrical circuits and computer chips—they are eager to learn more.

Across the country, in Michele Bartlett's earth science class at Rundlett Junior High School in Concord, N.H., 8th grade students are participating in an international ozone monitoring project. Using filter-paper badges, students collect smog data locally and then share their findings via the Internet with students at 80 other schools around the world. Bartlett's students also graph and analyze the data. In the process, they learn vocabulary such as "nitrous oxide" and "parts per billion" without having to resort to rote memorization. Students also submit their data to the Air Quality Board, the governor, and the National Student Research Center. Because they care about air quality, and because they are collecting real data to be shared with others, students take their work seriously.

LINDA ARMSTRONG

Giving students experiences with real phenomena is central to the reform agenda.

If these students had been born only a few years earlier, their experiences in learning science might have been starkly different. Science education has traditionally followed the "teaching by telling" approach. Teachers have relied heavily on textbooks and lectures to convey large quantities of information, and students have been expected to memorize reams of facts and terminology. Hands-on experiences have typically been limited to "cookbook labs" with outcomes known in advance, not real investigations. In most classrooms, science has been presented as an inert body of knowledge to be assimilated, rather than a process of inquiry and a way to make sense of our world.

The traditional "telling" approach has allowed science teachers to cover a great many topics. But the quality of student learning that it has yielded has proven disappointing, experts in the field say. Many students can parrot what they've been taught, but their understanding of science concepts is often seriously flawed. Students' prior misconceptions, for example, stubbornly resist change.

Even on standardized tests, which emphasize recall over reasoning, student achievement has been lackluster. According to the most recent data from the National Assessment of Educational Progress, "Compared to 1969–70, average [science] achievement in 1992 was higher at age 9, essentially the same at age 13, and lower at age 17."

Perhaps worse, the "telling" approach bores and alienates many students, who stop taking science courses as soon as possible. As a cohort of students progresses through high school, the number enrolled in science classes drops by roughly half each year, experts say. And the students who typically stick with science courses and succeed in them—students who are highly verbal and have good memories—do not necessarily make the best scientists.

Faced with these problems, the science education community is working zealously to reform itself. Major organizations—such as the National Science Foundation (NSF), the National Science Teachers Association (NSTA), the American Association for the Advancement of Science (AAAS), and the National Academy of Sciences—are vigorously promoting the kinds of hands-on, inquiry-based activities described at the beginning of this article.

Reformers have set forth, in detail, a new vision for science education. Strong themes in the reform literature include the following:

- Learning of concepts should be emphasized over memorization of terms and facts.
- Students should have ample opportunities for hands-on learning. Concrete experiences with actual phenomena should precede more abstract lessons.
- Science instruction should be inquiry-based, at least in part. Students should have opportunities to pose their own questions, design and pursue their own investigations, analyze data, and present their findings.
- Teachers should explain concepts thoroughly before introducing the terminology associated with them, to ensure real understanding rather than parroting.
- Teachers should teach fewer concepts, in greater depth, rather than covering a great many topics superficially. ("Less is more.")

A Snapshot of the Field

How does science education play out on a day-to-day basis, in classrooms across the United States? Findings from the 1993 National Survey of Science and Mathematical Education, conducted by Horizon Research, Inc., with funding from the National Science Foundation, shed light on this question. The survey gathered data from approximately 6,000 U.S. teachers of math and science in grades 1–12 about their beliefs and practices. It also gathered data from department heads and lead teachers about their schools' science programs. Some illuminating findings follow.

Science Instruction

- Although use of hands-on activities has increased since the mid-1980s, science teachers still rely heavily on lectures and textbooks.
- The vast majority of science classes use one or more commercially published textbooks or programs, including 95 percent of middle and high school science classes. At the elementary level, 75 percent of science classes use published textbooks or programs, down from 86 percent in 1986.
- Looking across all science classes, the largest proportion of class time is devoted to lecture and discussion (38 percent), followed by hands-on or laboratory work (23 percent), individual seatwork (19 percent), and nonlaboratory small-group work (10 percent), with the remaining 10 percent of time spent on non-instructional activities.
- Sixty percent of high school science and math classes listen and take notes during presentations by the teacher on a daily basis; 94 percent do so at least once a week.
- More than 60 percent of high school science classes never take field trips, 54 percent never use computers, and 43 percent never work in class on science projects that last at least a week.

Teachers' Goals

- According to teacher reports, the most heavily emphasized objectives in science classes are learning basic science concepts (heavily emphasized in 83 percent of science classes overall), increasing awareness of the importance of science in daily life (77 percent), and developing problem-solving and inquiry skills (74 percent).
- Approximately 20 percent of science classes in each grade range put heavy emphasis on preparing students for standardized tests.
- Teachers in classes with high proportions of minority students are more likely than others to emphasize preparing students for standardized tests, and less likely to aim toward preparing students for further study in science and math.

Time Devoted to Science

- In elementary classes, an average of only about one-half hour per day is spent on science instruction. This figure has increased slightly over the past 15 years.
- Students are typically required to take two years of science in high school.

Diversity Issues

- Non-Asian minority students are particularly likely to "drop out" of science and math course taking.
- The proportion of science and math teachers who are themselves members of minority groups is very low—only about 11 percent in the elementary and middle grades and 7 percent at the high school level, at a time when roughly 30 percent of students belong to minority groups.

Equipment Needs

- Many science teachers indicated that certain kinds of equipment they need are unavailable. The most frequently cited needs were for running water, electrical outlets, gas for burners, and hoods or air hoses in laboratories, as well as videodiscs and CD-ROM players.

Adapted from *A Profile of Science and Mathematics Education in the United States: 1993*, by Iris Weiss of Horizon Research, Inc., 111 Cloister Court, Ste. 220, Chapel Hill, NC 27514-2296. ●

JOHN MCNAMARA

Hands-on approaches will attract a broader range of students to science courses, reformers believe.

- Students should have opportunities to *apply* science knowledge and to make connections between what they learn and their everyday lives.
- Teachers should build on students' prior understandings and prod them to rethink their misconceptions.
- All students should become science literate, not just the college-bound. Schools should prepare science-literate citizens, not just future scientists.
- Educators should begin to integrate the various science disciplines (biology, chemistry, physics), as well as integrating science with other subject areas.

The "overarching theme" of these reform ideas is constructivism, says Dennis Cheek, who coordinates mathematics, science, and technology for the Rhode Island department of education. The focus is on "allowing students to make meaning for themselves" through active learning experiences, rather than just barraging them with information.

These reform ideas are "absolutely vital," says Anthea Maton, a science education consultant from Oklahoma City. There's a big difference between teaching from the textbook and making sure students grasp concepts, she asserts. Students who only *know* the science they're learning and students who truly *understand* it are "poles apart."

Maton cites the example of a class she observed where a student incorrectly used the term *inertia* instead of *momentum*. If teachers introduce these terms without having students explore and discuss the associated concepts thoroughly, she says, students' understanding of the terms may be limited to "if something moves, it has it."

Inquiry-based learning yields deeper understanding because it focuses on the question "How do we know?" says Gerhard Salinger, a program director at the National Science Foundation. Although teachers can simply *tell* students facts—for example, that the earth has seasons because it rotates on a tilted axis—students will understand (and remember) such concepts better if they explore why we believe them to be true. Experimenting with a flashlight and tennis balls, he suggests, can help students truly understand what causes the seasons—and gives the teacher an opportunity to confront the misconception that, during winter, the entire earth moves farther from the sun.

These reform ideas are not new; experts in the field readily admit. Yet, from his visits to classrooms, Cheek has found "there's still an awful lot of 'chalk and talk' going on." Many teachers still place more emphasis on maintaining "control and quiet" than on using active, hands-on approaches that help students gain real understanding. Implementation of these ideas has a long way to go.

Major Reform Efforts

Several massive reform efforts are aimed at changing that situation. The National Science Foundation, for example, is funding statewide systemic initiatives to promote reform. Other high-profile efforts include NSTA's Scope, Sequence, and Coordination project, AAAS's Project 2061, and the new National Science Education Standards project.

Scope, Sequence and Coordination of Secondary School Science (SS&C) is a reform effort of the National Science Teachers Association (NSTA). SS&C recommends that all students study each science discipline—biology, chemistry, physics, earth and space science—every year for six years (in grades 7–12).

This approach is a radical change from the prevailing "layer-cake curriculum," in which students study earth science in 9th grade, biology in 10th grade, chemistry in 11th grade, and physics in 12th grade. (More than half of all students don't take a science course after 10th grade, and only 19 percent take a course in physics, according to NSTA literature.) The SS&C approach spreads out the study of each science discipline over several years. It also features hands-on, inquiry-based instruction.

When students study each science discipline beginning in the middle grades, courses like chemistry and physics don't seem so "foreign" to them when they are juniors and seniors, says Thomas Sachse, executive director of the California Science Project, a statewide staff development network. And because students learn these disciplines gradually, without complex math at first, they develop "an affinity, not a fear" for them, he adds.

SS&C is "trying to provide a substantial level of understanding [in each science discipline] for all students, in a society where people believe that most students can't learn it," says Bill Aldridge, NSTA's executive director. Most people, including science educators, sincerely believe that science at certain in-depth levels can't be learned by everyone, he charges. Yet the evidence against this belief—from countries that teach demanding science to a far greater proportion of students than the United States does—is "overwhelming," he says.

Typical science courses put "all the abstractions at the beginning" and emphasize the memorization of facts and processes—an approach that "basically sorts people out," Aldridge says. By contrast, SS&C modifies the curriculum in accordance with the research on how students learn. As a result, "essentially all kids can learn it."

Since 1990, SS&C has been implemented at the middle-school level at six pilot sites. Now, a newly launched study of 15 high schools implementing SS&C will "put it to the test," Aldridge says. He hopes the independent evaluation will show "dramatic" results, especially for minority students. Just showing a positive effect will not spur broad-scale change, he believes.

Project 2061, a long-term reform initiative of the American Association for the Advancement of Science (AAAS), addresses science, mathematics, and technology, says Jo Ellen Roseman, the Project's curriculum director. It focuses on the curriculum, because curriculum is "central to the reform effort." The Project's philosophy is set forth in two major publications, *Project 2061: Science for*

All Americans and *Benchmarks for Science Literacy*.

Science for All Americans, published in 1989, defines "a clear set of adult literacy goals in science, mathematics, and technology for everyone," Roseman explains. *Benchmarks for Scientific Literacy*, released in 1993, suggests concepts to introduce at grades 2, 5, 8, and 12 that would constitute "reasonable progress" toward the literacy goals. Where the benchmarks and the draft national standards for science education overlap (natural science and technology), they are "overwhelmingly the same," Roseman says, and thus mutually reinforcing. (For more on the national standards, see box, below.)

According to *Science for All Americans*, Project 2061 envisions a science curriculum in which

- the amount of detail that students are expected to retain is considerably less than in traditional courses, so that important concepts can be explored in some depth. Ideas and thinking skills are emphasized at the expense of specialized vocabulary and memorized procedures.
- boundaries between traditional subject-matter categories are softened and links are emphasized, so that students will appreciate connections among ideas.
- some topics rarely found in school curriculums are addressed, including the nature of the scientific enterprise, important episodes in the history of science and technology, and the major conceptual themes that run through almost all science thinking.

Project 2061 recognizes that curriculum reform is "necessary but far from sufficient" to transform science education, Roseman says. To support other aspects of reform, AAAS is producing computer disks of descriptions of recommended professional development resources and teaching materials. (The former will be available by

National Standards Seen as a Catalyst for Reform

Science, like many other subject areas, will soon have a set of national standards to bolster the efforts of reformers. Developed by the National Research Council (an agency of the National Academy of Sciences and the National Academy of Engineering), the *National Science Education Standards* have been widely disseminated in draft form. The final version is expected to be published this fall.

Unlike some similar efforts in other subject areas, the science standards take a systemic approach. Beyond spelling out important science content, they describe the kind of teaching, professional development, and assessment the field should provide. The draft document also includes "program standards"—criteria for judging school science programs—and "system standards," which address resources and coordination at the state and federal levels.

Not surprisingly, the science standards promote the major themes in the reform literature. The standards document states the following principles, among others, at the outset:

- All students should have the opportunity to attain higher levels of scientific literacy than they do currently.
- All students will learn all science in the content standards.
- All students will develop an understanding of science that enables them to use their knowledge in personal, social, and historical contexts.
- Learning science is an active process.
- For all students to understand more science, less emphasis must be given to some science content and more resources must be devoted to science education.

Development of the standards began in 1992, with broad input from scientists and science educators. The fourth and last round of review began in December 1994. Close to 40,000 copies of the draft document have been distributed, half to individuals and half to focus groups of teachers, professors, businesspeople, and scientists.

"I am relieved to say that most of the responses are very positive," reports Angelo Collins, director of the National Science Education Standards Project. One complaint some reviewers have made, however, is that the draft document is too long. "No one has suggested something to take out, though," Collins notes wryly. Other reviewers have criticized the standards for failing to capture adequately the *quantitative* aspect of science—a concern that will prompt some revisions, Collins says.

The content standards focus on fundamental concepts—the "big ideas" such as motion, force, matter, energy, evolution, and genetics—rather than bogging down in numerous topics, factoids, and technical words, says Rodger Bybee, who served as chair of the working group on science content standards. Bybee is associate director of the Biological Sciences Curriculum Study (BSCS).

The content standards also attempt to broaden science learning beyond a narrow focus on life, earth, and physical sciences, Bybee says. Therefore, they include several other categories as well: science and technology; science in personal and social perspectives; history and nature of science; unifying concepts and processes; and science as inquiry.

According to the standards document, inquiry "involves making observations, posing questions, examining books and other sources of information to see what is already known, planning investigations, reviewing what is already known in light of experimental evidence, proposing answers and explanations, and communicating the results."

The content standards represent fundamental concepts that *all* students should grasp, Bybee says. "We're focusing on the question, 'What should all citizens know and be able to do?' not 'What do students need to know to get into graduate school?'"

The standards are "silent" on the question of how the curriculum should be organized, Bybee points out. They do not pass judgment on the layer-cake curriculum, interdisciplinary approaches, or AP courses, for example. States and districts must determine what form the curriculum should take, he says.

Teaching Standards

Although the science standards also address teaching, they *don't* say, "This is the one way to teach," notes Karen Worth, who served as chair of the working group on science teaching standards. Worth is a senior associate at the Education Development Center and a faculty member in the graduate school of education at Wheelock College.

the end of this year; the latter, by late 1996. Roseman predicts. Two other publications, *Designs for Science Literacy* and *Blueprints for Reform*, will help educators design K–12 science curriculums and pursue systemic reform, respectively.

What Teachers Need

The national science organizations are calling for reform, and teachers are listening. Do they like what they hear?

Teachers, as a group, have mixed feelings about the reform agenda (see box, p. 6). Those in the upper grades tend to be more resistant. The teachers interviewed for this article—all of whom have received Presidential Awards for Excellence in Science—were enthusiastic about the reform ideas but described a variety of obstacles to implementing them.

To take a hands-on approach, teachers "constantly have to put together materials and activities," says Alfred Benbenek, who teaches 5th grade at Holt Elementary School in Whitman, Mass. Given small budgets for science materials, teachers have to "beg, borrow, and steal" materials such as cups, zip-lock bags, wires, batteries, and aluminum foil, he says. Because these things wear out, teachers are in constant need of them.

Teachers are eager to do hands-on activities, says Jane Carey, who teaches 2nd grade at Lancashire Elementary School in Wilmington, Del. Teachers are held back, however, by lack of direction about what to do, lack of materials (without scrounging), and lack of training, which makes them "hesitant to jump in."

Carey teaches a unit on "sinking and floating" in which students test a variety of objects to see whether they sink or float, then try to turn a "sinker" into a "floater" and vice versa. The class makes a chart of materials and their properties. Then students apply what

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Because the standards promote science as inquiry, they ask teachers to help students become inquirers who learn basic concepts in the context of investigations. Worth acknowledges that this role will not appeal to all teachers. "There are teachers out there who still do not believe philosophically in teaching for understanding rather than [dispensing] information," she says. "If you're in the 'they-really-should-know-these-facts' camp, you won't want to do this." Teachers who want students to construct their own understandings, on the other hand, will find the standards "an important validation," she believes. These teachers "tend to be viewed as the fringe," she says. "Now they will be validated as the center."

The bottom-line message of the assessment standards is that educators should collect information about what students understand for a *variety* of purposes—not just to assign grades, says Audrey Champagne, who served as chair of the working group on science assessment standards. Champagne is a professor of chemistry and education at the University of Albany (SUNY).

The new emphasis on inquiry and reasoning skills poses a challenge for assessment, she notes. It's relatively easy to assess whether a student can use a balance to measure mass, for example—it's harder to assess whether the student can figure out that she *needs* to use a balance. Yet both kinds of abilities are important to assess.

Nothing New?

"To some degree, you could say there's nothing new in the standards," says Harold Pratt, who worked on the standards development team for more than two years. A former director of curriculum in Jefferson County, Colo., Pratt now directs an elementary science program for BSCS. The ideas reflected in the standards have been widely accepted in the field for many years, Pratt maintains. Yet "they are far from being implemented," he says. Implementation has been "our Waterloo."

The standards should be neither slavishly followed nor dismissed out of hand, Worth says. "This is not a perfect document, and it should not be followed perfectly—but it should be seriously considered."

The response of many teachers to the standards, however, is "You must be kidding," Worth concedes. Teachers' resistance is not so much a reaction to the philosophy embodied in the standards as to the fact that assessments and resources are not yet aligned with that philosophy. Even some teachers who fully endorse the standards say, "I'm not going to touch these until the rest of the world agrees and provides the resources we need for implementation." Worth calls this attitude "a well-founded cynicism."

Educators should not expect that teachers will pick up the standards and use them directly, Pratt says. "This is not a document that tells you what to do in your classroom tomorrow." The standards are "not a how-to document," Worth agrees. Instead, they are "a guide for decision making"—a set of criteria against which to weigh policy decisions, from the school level to the national level.

Perhaps unfortunately, the scope of the national standards does not, for the most part, extend to higher education, Pratt notes. "That piece is yet to be done—and it's an important part of the system."

The standards are one strategy for moving reform forward—not a panacea, Pratt says. But they will serve as "a catalyst for improvement," he believes. "They will focus our attention." Science educators should get acquainted with the standards and use them as a focus of dialogue and discussion, he advises.

Although the standards document is only in draft form, "the signs are that it's already had a big impact," Collins says. The standards are exerting an influence on state curriculum frameworks, textbook publishers, and professional development offerings, she says. The major organizations in science education are all promoting their implementation, she adds. For example, NSTA has already published *A High School Framework for National Science Education Standards* to help educators create programs based on the standards.

"The harder task lies before us," Bybee cautions. "It was relatively easy to develop the standards. But translating them into programs to help all students achieve higher levels of scientific literacy will be a tremendous task," he says. The "scaling up" will require a concerted, national effort. States and districts will have to devote resources to the endeavor, as will the U.S. Department of Education, the National Science Foundation, organizations such as NASA, and private foundations. "It's their move now." ●

The final version of the standards, anticipated next fall, will be sold by National Academy Press. For more information, contact the National Science Education Standards Project, 2101 Constitution Ave., N.W., HA 486, Washington, DC 20418; (tel.) 202-334-1399.

they've learned by creating a classroom aquarium. "If teachers had the time and resources," more ideas like this would flourish, Carey says.

Judy Morlan, who teaches 6th grade at Brownell Middle School in Grosse Pointe Farms, Mich., finds it "very difficult" to put constructivist principles into practice in her science teaching. She is frustrated by "a tightly packed curriculum" that she is held closely to. Because she must cover all the objectives, Morlan can't take the time to teach certain topics in depth, as she would like to do. In addition, trying to identify the misconceptions of a classful of children, and then working to change them, is very time-consuming.

"I feel like I'm in the middle," she says, because she is forced to compromise. "I'm a part-way person."

Morlan uses active learning "to make an impression on kids with the important things." For example, she has her students pace out the relative distance of the planets from the sun. "They respond to this sort of thing," she reports. She feels her efforts have been worthwhile when, for instance, a student exclaims, "Oh, my gosh—I didn't realize Pluto was *that* far from the sun!"

High school teachers are reluctant to change because they still feel accountable to colleges and universities, says Margo Murphy, who teaches 9th-grade environmental science at Georges Valley High School in Thomaston, Maine. Although Murphy herself doesn't teach from a textbook, most high school science is textbook-driven, she says. To create another kind of course demands "an enormous amount of work" from a teacher. It takes "a huge amount of time to convert" to an inquiry-based approach, she says.

Naturally, given these challenges, reformers are calling for more professional development for teachers of science. Teacher training is a big component of reform proposals, says Matos. "Nobody is advocating just *telling* teachers to teach this way."

Reform should *focus* on teacher education—both preservice and inservice, says Marvin Druger, chair of science teaching at Syracuse University and president of NSTA. "That's where the action should be." Many reformers are urging that undergraduate science courses become inquiry-based as well. Future teachers who have learned science in 300-seat lecture halls will not know how to foster active learning, they assert.

Teachers' Attitudes Toward Reform

Do teachers embrace the reforms in science education that national organizations are advocating? The 1993 National Survey of Science and Mathematical Education provides some insights. Conducted by Horizon Research, Inc., with funding from the National Science Foundation, the survey asked approximately 6,000 U.S. teachers of math and science in grades 1–12 about their training, pedagogical beliefs, and instructional practices. Here are some highlights from the findings.

Teachers Support Some Reform Ideas . . .

- Nearly all teachers believe hands-on activities should be part of science instruction.
- Most teachers believe that science instruction should provide students with concrete experiences before exposing them to abstract treatments. About 84 percent of high school teachers, and more than 90 percent of teachers at other levels, hold this view.
- Most teachers believe that students learn best when they study science in the context of personal or social applications. More than 90 percent of teachers at the elementary and middle school levels hold this view, as do 86 percent of teachers at the high school level.
- Most teachers support the use of cooperative learning in science classes. More than 80 percent of teachers at the high school level, and more than 90 percent of teachers at other levels, hold this view.

. . . But Resist Others

- Teachers are divided on the idea of emphasizing "depth over breadth." Only about 70 percent of elementary and middle grade teachers, and fewer than 60 percent of high school teachers, agree that science and math instruction should provide deeper coverage of fewer concepts.
- Many teachers resist the advice of reformers to teach science concepts *before* teaching the terminology associated with those concepts. Nearly one-third of teachers in grades 1–4, increasing to more than half of high school science teachers, indicated that "it is important for students to learn basic scientific terms and formulas before learning underlying concepts and principles."
- Although the reform literature calls for de-emphasizing factual learning in science, many teachers report that they emphasize this objective in science classes. Half of elementary science classes, and nearly 2 out of 3 in the middle and high school grades, put heavy emphasis on learning "important terms and facts in science."
- Many teachers doubt that heterogeneous grouping is the way to ensure success for all students. Roughly 3 in 10 teachers of grades 1–4 believe that students learn science and math best when grouped with peers of similar abilities. At the high school level, more than 7 out of 10 teachers hold this view.
- Although reform advocates tend to be critical of science textbooks, most science teachers are pleased with the quality of their textbooks. About 3 out of 4 teachers rate their science textbooks "good" or better.

Attitudes Differ by Grade Level

- Elementary teachers tend to be confident in their ability to use reform-oriented strategies such as cooperative learning. However, many do not feel confident in their ability to teach a number of elementary science content areas.
- High school teachers are more likely to have extensive preparation in their subjects, but they are less supportive of reform-oriented teaching techniques, less confident in their ability to use them, and less likely to do so in their classrooms.

Adapted from *A Profile of Science and Mathematics Education in the United States: 1993*, by Iris Weiss of Horizon Research, Inc., 111 Cloister Court, Ste. 220, Chapel Hill, NC 27514-2296. ●

Science courses have been too abstract and too mathematical from the outset, reformers charge.

JOHN McNAMARA

In the reform literature, "textbook-driven" has become a pejorative term. Reformers of science education have criticized textbooks for abetting the "teaching by telling" approach.

Science texts in the United States differ from those used in other countries, says Senta Raizen, director of the National Center for Improving Science Education. U.S. textbooks "treat many topics in a scattershot fashion," whereas those in other countries treat fewer topics, in greater depth, and include far less review.

But U.S. texts are beginning to change, Raizen says. Textbook publishers try to follow state guidelines, she notes. "They're not nasties." But they can't prescribe how motivated teachers will be to encourage students' own investigations rather than lecturing from the textbook, she adds.

One 11th-grade textbook that anticipated the reform movement is *Chemistry in the Community*, developed in 1982 by the American Chemical Society. Now in its third edition, the book is "still considered rather nouveau," says Sylvia Ware, director of the Society's education division.

Chemistry in the Community was designed to correct the "mismatch" between chemistry instruction and students, Ware says. Most high-school chemistry serves best as an introduction for those who intend to earn a bachelor's degree in the subject— but of course most students won't do this," she points out. Instruction is too abstract and too mathematical, Ware charges. "Chemistry doesn't have to be a quantitative discipline from Day One."

Unlike a traditional text, *Chemistry in the Community* examines issues in the community, to teach "chemistry for citizenship." The book is designed around eight issues: water needs, conserving chemical resources, petroleum, food, nuclear issues, air, health, and industry and its role in society.

Students using the text make lots of decisions and apply chemical knowledge, Ware says. In the first unit, for example, a scenario describes a "fish kill" in an imaginary river. Students investigate why the fish died, then hold a town meeting, where the facts come out. Then they must decide how to handle the problem.

"We're trying to rehabilitate the utilitarian," Ware says. "Knowledge can be useful—that's not a negative! If knowledge were only abstract, we'd never have got out of caves," she jokes.

Going Too Far?

Despite widespread enthusiasm for reform, some science educators fear that reform ideas may be taken to extremes.

"There seems to be a [misconception] that all science at all grade levels should be learned through inquiry," says Audrey Champagne, a professor of chemistry and education at the University of Albany (SUNY). Champagne finds this view too one-sided. In the early grades, inquiry-based learning can help students develop knowledge and reasoning skills that will enable them to learn in more traditional ways ("book learning") in the upper grades, she believes.

The heavy emphasis on inquiry may be an overreaction to the current overemphasis on facts, Champagne says. "Education in the United States is characterized by pendulum swings to the extreme."

Inquiry-based instruction is "a good idea in moderation," says David Haury, director of the ERIC Clearinghouse for Science, Mathematics, and Environmental Education. As students, "we all benefit from a *mixture* of experiences."

In today's climate of reform, there is a readiness to denigrate textbooks and lectures, Haury says. But when students' curiosity is aroused, they are receptive to reading or listening. And if students are to become science literate in 12 years of schooling, "some things must be told to them." Therefore, teachers should seek a "happy balance," Haury advises. "You don't have to throw away one [approach] to do the other."

Haury also has concerns about the "less is more" philosophy. Teachers embrace the idea, he says, but they are uncomfortable with having to defend the practice. Teachers are placed in an awkward position when they must respond to administrators or parents who ask, "Why aren't you teaching this formula or that set of facts?"

Paring down the curriculum in keeping with the "less is more" philosophy ought *not* to be done on an individual-teacher basis, says Carolee Matsumoto of the Education Development Center. It's "risky" for teachers to take a stand on their own; they are too vulnerable to attack. Instead, the school or district should develop a scope and sequence with input from science experts, teachers, parents, and others, she says.

Some science teachers are uncomfortable with the notion of de-emphasizing facts and terms. Paul Pomeroy, who teaches 12th-grade physics at Archmere Academy in Claymont, Del., believes the reform ideas are "incredibly good in many ways." But he also thinks the heavy emphasis on teaching concepts is "a misguided notion." What started as a push to *include* hands-on activities and opportunities to conceptualize is being "misconstrued by many as the only good way to teach science," he says.

Pomeroy agrees with reformers that "memorizing and spitting stuff back is horrible science." But students still need to know

terms, facts, and how to compute, he says. And "there are times you have to get into the theory and muck through it."

College-bound students still need to develop the skill to "regurgitate" information, says C. Ford Morishita, who teaches biology at Clackamas High School in Milwaukie, Ore. Teachers of Advanced Placement (AP) courses *must* emphasize coverage and teach prescribed labs, he adds. "You can't cut content or you're cutting students' throats on AP exams."

Raizen also advocates using a mix of instructional strategies. "I'm someone who wants to make sure we don't throw out older styles of teaching," she says. However, most classes are still textbook- and lecture-oriented, she points out. "We're far from having the pendulum swing too far—yet."

The reform notion of extending science instruction to a much broader range of students also raises concerns.

Schools can't teach just a "literacy curriculum," says Morishita. "Bright kids need another level of opportunity." He worries that schools might phase out advanced single-discipline science classes and research opportunities. "We can't do 'science for all' at the expense of the high achievers," he says.

Pomeroy also fears that "in making sure every student gets some science, we may sell the top third of students short," by "diminishing the intensity" of their instruction. He is disturbed by the prevalent attitude that bright students will thrive, regardless of their school experiences. "A good student needs to be pushed too—and farther," he says.

"Science for all" is the subject of "a raging argument," Salinger of NSF says. One way of teaching that challenges *all* students—even "the really bright kids"—is to pose open-ended "design problems," he says. For example, a teacher could ask students to design a container to get a baked potato home hot from a fast-food restaurant. This problem requires students to set a standard for what "hot" is, measure the thermoconductivity of various materials, consider structural rigidity, and address environmental concerns. Different students could be encouraged to design their solutions under different sets of constraints, depending on their ability, Salinger adds.

Moving Beyond Experience

The reform movement in science education is promoting many very good ideas that make logical sense, Haury says. But how do educators actually put them into practice? "None of us have experienced it," he says of the new vision of active learning. "Trying to get large communities of people to think beyond the boundaries of their own experience—that's the challenge." ●

Resources

The following organizations can provide resources for improving science education.

American Association for the Advancement of Science, 1333 H St., N.W., Washington, DC 20005; (tel.) 202-326-6666; (fax) 202-842-5196.

National Science Teachers Association, 1840 Wilson Blvd., Arlington, VA 22201-3000; (tel.) 703-243-7100; (fax) 703-243-7177.

ERIC Clearinghouse for Science, Mathematics, and Environmental Education, The Ohio State University, ERIC/CSMEE, 1929 Kenny Rd., Columbus, OH 43210-1080; (tel.) 614-292-6717.

National Science Resources Center, Arts and Industries Bldg., Room 1201, Smithsonian Institution, Washington, DC 20560; (tel.) 202-357-2555; (fax) 202-786-2028. The NSRC collects and disseminates information about exemplary teaching resources, develops innovative curriculum materials, and sponsors outreach activities to help school districts develop and sustain hands-on science programs.

Eisenhower National Clearinghouse for Mathematics and Science Education, The Ohio State University, 1929 Kenny Rd., Columbus, OH 43210-1079; (tel.) 614-292-7784; E-mail: info@enc.org. The Clearinghouse maintains an up-to-date and comprehensive listing of mathematics and science curriculum materials.

National Association for Science, Technology, and Society (STS), Pennsylvania State University, 133 Willard Bldg., University Park, PA 16802; (tel.) 814-865-3044; (fax) 814-865-3047. NASTS promotes examination of the impact of science and technology on society and the environment.

National Center for Improving Science Education, 2000 L St., N.W., Ste. 603, Washington, DC 20036; (tel.) 202-467-0652; (fax) 202-467-0659; BITNET: sentar@gwuvm.gwu.edu. NCISE provides a range of products and services to policymakers and practitioners who are working to strengthen science education.

Biological Sciences Curriculum Study, Pike's Peak Research Park, 5415 Mark Dabling Blvd., Colorado Springs, CO 80918; (tel.) 719-531-5550. BSCS is a nonprofit organization that designs curriculums in the sciences.

Education Development Center, 55 Chapel St., Newton, MA 02158; (tel.) 617-969-7100. EDC is a nonprofit organization that does research and development work in education, including curriculum development. ●

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